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LCA FOR ENERGY SYSTEMS AND FOOD PRODUCTS · CASE STUDY

Life cycle assessment of integrated food chains—a Swedish case study of two chicken meals

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Abstract
Background, aims, and scope Food is a vital human need that not only provides essential nutrition but is also a key part of our social life as well as being a valued sensory experience. However, food, or rather the production chain of food, from primary production (agriculture/aquaculture/fishing) to consumer and beyond, also results in some form of environmental impact, as does transport between steps. There are several life cycle assessment studies of food products, most of them analysing the impact of the food chain of single food items. Still, detailed studies of complete meals are less frequent in the literature. In the Swedish study presented in this article, the environmental impacts of two different chicken meals (homemade and semi-prepared) were analysed. The aim of the study was to gain knowledge of the environmental impact of integrated food chains and also to explore the effect of improvement measures in the post-farm systems. To this end, two chicken meals were chosen for analysis, with two scenarios for each meal; the first scenario reflects the present conditions of the food chain, and the second scenario incorporates a number of improvement actions in the stages after the farm.
Materials and methods Input data to the model were based mainly on previous life cycle assessment (LCA) studies of Swedish food products and studies on wastage and consumer transport. Food engineering data and information from producing companies were used for modelling the industries. The improvement scenario was constructed using insight from a preceding LCA study of a meatball meal (Sonesson et al., *Ambio*, 34:411–418, 2005a) along with goals set out by a Swedish agreement between representatives from national and regional government, food industry sectors and retailers. The impact assessment was conducted according to Lindfors et al. (*Nordic guidelines on life cycle assessment*, The Nordic Council of Ministers, Copenhagen, Denmark, 1995), and the following environmental effects were included: global warming potential, eutrophication potential, acidification potential, photochemical ozone creation potential, and use of primary energy carriers and secondary energy.
Results In terms of energy use, the largest part is used in the steps after the farm for both meal types. Hence, the changes made in the improvement scenario have a significant impact on the total energy use. For the homemade and semi-prepared meal, the reduction is 15% and 20% respectively, not only due to less consumer transport and packaging but also reduction in industry (semi-prepared). Agriculture is also a significant contributor to emissions of greenhouse gases and eutrophying emissions; for the homemade meal, around 40% of the greenhouse gases originate from agriculture, and for the semi-prepared meal, the figure is 50%. The improvement actions with the greatest reduction in greenhouse gases are, again, less consumer transport and, in the case of the semi-prepared meal, the reduction in energy use in industry. Regarding eutrophication, more than 90% of the emissions originate from agriculture. Hence, the only improvement action that has an effect here is the utilisation of raw material downstream in the production chain; a slight reduction in waste still gives a notable reduction in overall eutrophic emissions.
Discussion There are two significant areas of research to reduce the impact of meals that are not explored in this study: choice of meal components and production methods

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in agriculture. However, the aim with this study was to explore if there are further ways of reducing the impact without going into these very complex areas, and our conclusion is that there are effective ways in the post-farm chain to cut emissions that, together with choices of diet and agricultural research, can significantly reduce the impact of our food consumption.

Conclusions Actions in the post-farm chain that can significantly reduce the environmental impact of a meal are less food thrown away in the household, fewer car trips to the supermarket (e.g. only once a week) and, for semi-prepared food products, more efficient energy use in the food industry. The study shows that consumer actions prove just as important as industrial actions.

Recommendations and perspectives Further research is needed to understand the mechanism for the disposal of food, i.e. the reasons for food being wasted, and the relationship between shopping frequency, retail location, size of packaging, etc. in order to reduce the impact of waste and consumer transport.

Keywords Life cycle assessment · Food · Meal · Sweden · Chicken · Environmental impact · Improvement

1 Background, aims, and scope

The food chain, from primary production to consumption and beyond, results in significant environmental impact. In Sweden, 20% of the total energy use in society can be allocated to the food supply system, the largest consumers being agriculture, the food industry and households, followed by transport, retail and packaging (SEPA 1997a). For eutrophication, agriculture is the largest source; approximately 50% of all eutrophic emissions in Sweden come from agriculture, the remainder originate mainly from sewage treatment and transport (which includes transport of foods) (SEPA 1997b,c,d). Approximately 28% of total emissions of greenhouse gases in Sweden come from the food system's production chain (SEPA 2004), 15% stems from the food system's use of energy and 13% is due to agricultural emissions.

There are numerous life cycle assessment studies of food products, most of them analysing the impact of the food chain of single food items; to give a few examples, studies have been carried out on bread (Andersson and Ohlsson 1999), milk (Cederberg and Stadig 2003; Hospido et al. 2003), pork (Anonymous 2002) and cod (Ziegler et al. 2003). However, detailed studies of complete meals are less frequent in the literature (Sonesson et al. 2005a). Often, a selected environmental impact has been chosen for the analysis of different diets, e.g. energy or land use (Duchin 2005; Gerbens-Leenes and Nonhebel 2002). Unlike other materials, the environmental impact of food cannot be reduced by, for example, recycling or reuse. But there are possible improvements that can be made to ensure that our food consumption is in line with long-term sustainability. Kramer et al. (1999) have explored greenhouse gas emissions related to Dutch food consumption and identified which food product categories contribute most to these emissions. Similarly, Carlsson-Kanyama (1998) and Carlsson-Kanyama et al. (2003) present ways of reducing energy use and greenhouse gas emissions by changing diet. Conclusively, there are vast reductions in environmental impact to be made by changing which food products we consume (e.g. less animal protein in favour of vegetable protein). Furthermore, the aforementioned life cycle assessment studies of food products demonstrate that, for many environmental impacts, the largest contribution is caused by the primary production in the chain, namely agriculture/fishery. For agricultural products, this is especially the case for eutrophication, one of the most alarming environmental effects due to food systems as mentioned previously; almost all eutrophic emissions from the production system of an agricultural product come from agriculture. Therefore, improvement measures in agriculture can significantly reduce the overall impact of food products, which is the focus of many research groups. However, besides agricultural improvements and changing diets—are there other ways of decreasing the impact of our food consumption? This is an interesting avenue since changing eating behaviour, such as decreasing meat consumption, is difficult and sometimes interferes with cultural values as well as peoples' preferences. A preceding study to the work in this paper analysed the life cycle environmental impact of three different ways of preparing a meatball meal (Sonesson et al. 2005a); a comparison was made between a homemade meal, a semi-prepared meal and a ready-to-eat meal. Due to the significant contribution from the agricultural part of the life cycle of each meal, the raw material utilisation proved to be a vital factor when comparing the environmental impacts of the three meals. All food wasted at post-farm processing stages meant more food had to be delivered from the farm—this resulted in a higher environmental impact. Nevertheless, post-farm production steps were also of importance; energy efficiency in industry and households, consumer's transport, and packaging all proved to be key factors. Hence, the focus of the study presented in this article was to explore how a number of improvement measures in the post-farm system can affect the overall environmental impact of the food chain (including impacts from the farm). The aim was to investigate which measures result in the greatest reduction in environmental impact. In this study, two different meals based on chicken were chosen for analysis: one homemade and one semi-prepared meal. The primary goal was not to compare the meals but to

analyse the effects of improvement measures for each chicken meal. The motivation for exploring chicken-based meals was partly to broaden the knowledge on environmental impacts of meals by exploring another type of meal (other than meatballs) and partly for the reason that consumption of chicken has increased significantly in the past 10 years in Sweden (SPMA 2007). Furthermore, semi-prepared and ready meals are increasingly becoming a natural part of people's lives; it is estimated that two thirds of hot meals eaten in Nordic households are home-cooked, while one third is pre-prepared (Ahlgren 2004), and more knowledge about the impacts of these types of meals is needed.

This work is part of Food 21, a Swedish research program working within the area of sustainable food production. The overall long-term goal of the Food 21 program is to define optimal conditions for sustainable food production that generate high-quality food products (Food 21 2004).

2 Materials and methods

The environmental impact of each meal has been analysed with life cycle assessment methodology. The most important aspects of the method are summarised in this paper; further details are found in a data report (Sonesson and Davis 2005).

2.1 Meals

The study started with discussions with stakeholders in the food production chain to gather their input on interesting meals and improvement measures to analyse (food industries—Findus, Procordia/Orkla, Swedish Meats; retailer—COOP; consumer organization—The Stockholm Consumer Cooperative Society). Two different meals were chosen for analysis. Both meals are based on chicken and potatoes, as these are two very common ingredients in Swedish diets. Moreover, consumption of chicken has doubled over the last 10 years in Sweden; the average consumption per capita today is 13 kg/year (SMPA 2007). The meals consist of the following:

- Homemade meal: Chicken fillet fried in frying pan, oven-roasted potatoes and carrots, brown sauce and iceberg lettuce. Bread produced in a large industrial bakery, tap water and an apple are served with the meal.
- Semi-prepared meal: Chicken and potato hash. Hash is a traditional Swedish dish consisting of finely diced meat, potatoes and onions that are mixed together and fried; here, the dish is made with chicken. The hash is produced in industry and frozen. Frozen hash is fried in a frying pan. The meal is served with iceberg lettuce, bread produced in a large industrial bakery, a glass of milk and an apple.

Both meals are prepared for four people. It is assumed that the hash and the ingredients for the homemade meal are stored for a number of days before consumption. In order to simplify the calculations and due to data gaps, two components in the meals have been left out: vegetable oil and the brown sauce mix. This should be considered when interpreting the results. Still, the flows of these ingredients are negligible, and it is unlikely that they have a major environmental impact.

2.2 Functional unit

In the model, four portions of the meal is prepared and cooked at the same time, a situation which is quite common. However, the functional unit of the study is one meal for one person ready for eating, which facilitates communication of the results. Even though the two meals are different (the primary goal of the study was not to compare the two different meals but to analyse the environmental effects of improvement actions for both meals), they are similar in terms of how much energy they provide and how much of that energy comes from fat, protein and carbohydrates, respectively. The meals have been put together with the aim of fulfilling the recommendations for energy intake given by the Swedish national food administration; this explains the milk accompanying the hash meal to balance the nutrient intake. The recommendations state that a meal should provide one third of the daily energy intake with a total daily intake of 9.1 MJ for women and 11 MJ for men with moderate physical activity. Furthermore, the energy from fat should not account for more than 30% of total energy intake, protein should contribute 10–15% of the energy, and carbohydrates should contribute 50–55%. Table 1 shows to what extent these recommendations are fulfilled for the two meals. The nutritional energy has been calculated according to the database provided by the Swedish National Food Administration (http://www.slv.se). For the hash, nutritional data are taken from the product specifications.

2.3 Improvement actions

Two scenarios of each meal type have been analysed: one representing the production processes of today, and the other incorporating a number of feasible improvement measures in the post farm chain. In the selection of improvement measures, insight from the preceding meatball study were used (Sonesson et al. 2005a) as well as goals set out by Future Trade. Future Trade (see http://www.framtidahandel.se) is a Swedish alliance between represen-

Table 1 Components and energy provided in each meal (for one portion)

Components	Homemade	Semi-prepared
Chicken (g)	100	
Potatoes (g)	200	
Carrots (g)	150	
Hash, 16% chicken (g)		250
Milk (g)	75 (in sauce)	200 (to drink)
Bread (g)	80	120
Iceberg lettuce (g)	60	60
Apple (g)	100	100
Energy		
Total (MJ)	3.3	3.6
Contribution from fat (%)	29	31
Contribution from protein (%)	18	15
Contribution from carbohydrates (%)	50	55

tatives from national and regional government, different food industry sectors and retailers. The parties involved signed an agreement in 2003, which states the goals that are to be met in order to achieve more environmentally sustainable trade and transport of retail products. The actions that are incorporated in the study are reduced fuel consumption in truck transport, reduced energy use in industry, reduced energy use in retail, reduced raw material wastage in industry, reduced consumer shopping frequency, reduced amount of food packaging, reduced household wastage and reduced energy use for household appliances; the improvement actions are summarised in more detail in Table 2.

2.4 System boundaries

The system included in the analysis is depicted in Fig. 1. The differences between the scenarios are within the core system. Resource use and emissions per processed amount in the background system are the same in all scenarios, but the flows between the core system and the background system can vary. For the background systems, as energy production, the emissions and resource use to provide the input needed in the core system is calculated, the same for production of inputs to agriculture, as mineral fertilisers. In the household, the activities storing, cooking and washing up are included.

The sewage treatment in Fig. 1 represents treatment of effluents from industry; the sewage treatment of the remainders of the food after it has been eaten (i.e. urine and faeces) is not included. Ideally, it should have, but the system has been simplified here. In terms of comparing the meals, the effect of the sewage treatment will not differ greatly between the four scenarios, as their content of nutrients are similar (Sonesson et al. 2004). However, leaving this stage out means that the overall impact of each scenario is slightly underestimated. Another delimitation is the use of pesticides; this has not been considered due to lack of complete data on pesticide use for all the ingredients in the meals. Consequently, analysis of the toxicity caused by the production of the meals has not been performed.

2.5 Modelling

The approach used for the analysis is descriptive (attributional) life cycle assessment (LCA); regarding choice of data for processes in the background system in Fig. 1, we used average data as opposed to marginal data, e.g. the Swedish electricity used is assumed to be Swedish average electricity production mix. Arguably, during the transition to the improved scenarios, it is the marginal production that will change, but after a period of time, the market will have answered to the new demand, and it will no longer be the marginal production that is utilised but the average. Furthermore, the choice of average energy mix is a conservative one (i.e. the environmental benefits of the improvement actions are underestimated rather than exaggerated), which makes the results less prone to criticism and also easier to communicate.

In order to quantify the resource use, emissions and waste from the scenarios, the simulation model Systems Analysis of Food Processing and Transport (SAFT) was used; this was first developed and used in a project about dairy products (Sonesson and Berlin 2002). The model was complemented with models for other industrial processes, and the parts dealing with household energy use were improved. SAFT is basically a material flow model, i.e. a certain amount of food raw material enters the model at one end, the product flows through the system and all use of energy and emissions that occur as a result of the flow are calculated. Finally, consumed products leave the system at the other end. Throughout the SAFT model, vectors are used to describe all flows of material and energy between submodels. All emissions are also described by the same vector; emissions are calculated as single substances. In this study, the inflow was calculated as the required amount of raw material needed to get a certain amount of food on the table, taking into account all losses between farm and table. Regarding processes yielding more than one product, e.g. the mill, economic allocation has been used to partition the environmental burden between the products. However, for waste treatment, systems expansion has been used; produced heat from incineration in the waste and residual management replaces oil and coal (50/50). The rationale is that these fuels are the most probable to be either phased out or increased if changes in the district heating systems

Table 2 Actions included in the improved scenarios for both meals

Action	Motivation
Energy use in all truck transport is reduced by 20%	1. Future Trade has agreed to lower emissions drastically from food transport by 2025 2. Tests have shown that fuel consumption can be reduced significantly merely by changing driving behaviour (Johansson 2002b). This, in addition to technological advancements, should facilitate future energy reduction in transport
Energy use in the food industry (abattoir, dairy, mill, bakery and semi-prepared industry) and at packers (apple, lettuce, potato and carrot packer) is decreased by 25% per kilogram of produced food	1. Future Trade has set this target to be achieved by 2025 2. A dramatic reduction; however, the time-span is quite long which allows for the design and building of completely new industrial plants. Short-term reductions in already existing industries are likely to be smaller
Energy use in the retail sector is decreased by 25%	1. Future Trade has set this target to be achieved by 2025 2. Studies have shown that straightforward measures can save between 10% and 50% in refrigeration energy in food stores (Axell 2002)
Raw material wastage is decreased by 5% in the food industry (abattoir, dairy, mill, bakery and semi-prepared industry) and at packers (apple, lettuce, potato and carrot packer; $wastage_{improved}=wastage_{present}\times 0.95$)	Raw material utilisation has proven to be an important aspect when decreasing environmental loads from a meal (Sonesson et al. 2005a). The chosen decrease is a conservative improvement which should be an achievable development
Shopping frequency by car is reduced from 0.9 times a week at supermarkets and twice a week at neighbourhood retailers (Sonesson et al. 2005b), to only once a week at supermarkets	1. Consumer transport contribute significantly to the total environmental impact of foods (Roth 2000), hence, improvements are important 2. The present trend is towards large supermarkets outside the town centre, so this would be a realistic development. Furthermore, it is feasible to shop once a week for major foods, and then complement with fresh products, e.g. milk, bread and fresh fruit and vegetables, from the local shop (within walking distance)
Packaging is improved so that 10% less material per kg of product is required (without compromising the function of the packaging)	1. The weight of packaging per kg of product has become lighter over time; between 1993 and 2000, the weight of Swedish packaging decreased by 16% (Johansson 2002a) 2. The EU packagaging Directive 94/62/EC (EC 1994) combined with the CEN standard on prevention (CEN 2004) will compel companies to consider all light-weighting possibilities compatible with the required functions of the package
Households: 10% less wastage, oven requiring 25% less energy and use of ceramic hotplates	Reasonable development

occur. The emissions resulting from the incineration were calculated and included. At the same time, the emissions that would have occurred from combustion of oil and coal (50/50) to produce the same amount of heat were presented as negative emissions. The model and the parameters used are described in detail in Sonesson and Davis (2005).

2.6 Data and sources

Generally, the data used reflects the present food chain in Sweden. For the semi-prepared meal, it has been assumed that the chicken was produced in Sweden due to no data being available for imported chicken, i.e. data for Swedish poultry production has been used, even if this is not the case for most semi-prepared and ready meals containing chicken sold in Sweden. As input data to the model, a number of sources have been used, but results from several peer-reviewed LCA studies on Swedish food products are the most common source (Anonymous 2002). Food engineering data and information from producing companies have been used for modelling the industries. Finally, experiments have been carried out where no data were found in literature, as food preparation and wastage in households. The consumer's transport between retailer and households is modelled based on a survey of Swedish households (Sonesson et al. 2005b), showing that the average shopping frequency to external retailers is 0.9 times a week (distance 29 km, 83% of trips by car) and to neighbourhood retailers twice a week (distance, 11 km; 51% of trips by car). Cooking and storing in the household is modelled based on Sonesson et al. (2003). A summary of key parameters used in the analysis is given in Tables 3 and 4. In Sonesson and Davis (2005), all data used are presented along with references.

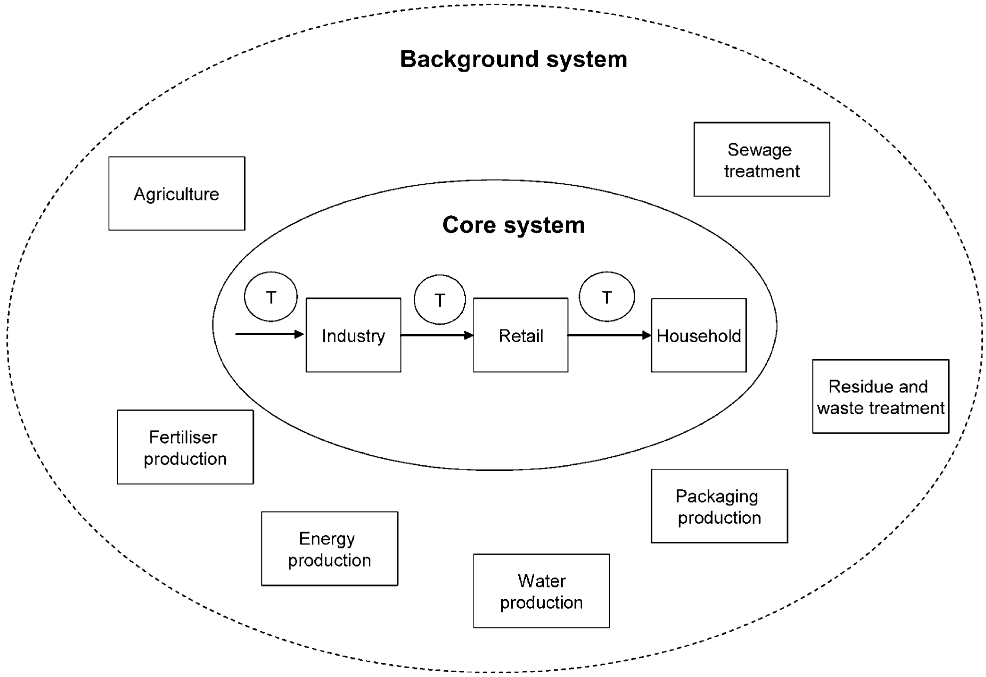

Fig. 1 Systems boundaries used in the study. *T* represents transport

2.7 Environmental impacts considered

The results from the simulation consist of a number of parameters, both emissions of different substances and use of resources, e.g. fuel. The emissions calculated were then transformed into environmental impact categories according to weighting factors recommended by Lindfors et al. (1995), see Sonesson and Davis (2005) for further details. The following environmental impact categories were adopted: use of primary energy carriers and secondary energy, global warming potential, eutrophication potential, acidification potential and photochemical ozone creation potential. The definition of primary energy carriers used in this paper is energy contained in raw fuels (e.g. fossil oil, uranium) and other unrefined energy sources, whereas secondary energy is energy that has first been converted to more convenient forms of energy such as electricity and cleaner fuels; due to the conversion factors, the total use of primary energy per meal will be higher than the total use of secondary energy per meal.

3 Results

Figures 2 and 3 show the energy use for each meal. For both meal types, the agricultural part is important, but the steps after the farm are even more energy demanding; for the homemade meal, about 65% is used after the farm; for the semi-prepared meal, post-farm activities account for as much as 75% of the total energy use. Consumer transport and packaging are quite significant for both meal types. As expected, household cooking is more energy demanding for the homemade meal, whilst more energy is used in industry to produce the semi-prepared meal. The significant energy use in industry in the semi-prepared meal is due to deep-frying of the potatoes and also the deep-freezing of the

Table 3 Data on storage, wastage and packaging used in the analysis

	Retailer waste (%)	Household storage	Household waste: storage/peeling	Primary and secondary packaging
Milk	1	3 days refrigerated	5%	25 g laminated cardboard/kg milk
Chicken	5	4 days refrigerated	4%	5 g PE and 15 g corrugated cardboard/kg chicken
Potatoes	2	5 days refrigerated	10%/20%	12 g cardboard/kg potatoes
Carrots	2	5 days refrigerated	10%/16%	5 g LDPE and 10 g corrugated cardboard/kg carrots
Hash	0.5	14 days frozen	0%	15 g LDPE/kg hash
Bread	10	Room temperature	10%	16 g PE/kg bread
Apples	10	Room temperature	20%/20%	3 g PP and 42 g corrugated cardboard/kg apples
Lettuce	10	5 days refrigerated	30%/10%	10 g LDPE and 9 g corrugated cardboard/kg lettuce

Table 4 Data on waste treatment used in the analysis

Waste treatment	Percent
Part of solid organic waste to incineration	95
Part of solid organic waste to landfill	5
Part of plastic waste to incineration	66
Part of plastic waste recycled	34
Part of cardboard waste to incineration	60
Part of cardboard recycled	40
Part of corrugated cardboard to incineration	16
Part of corrugated cardboard recycled	84

product. Keeping the product frozen is also the reason for the retail energy use of the semi-prepared meal. Treatment of residues (waste from abattoir and industry) and waste (from households) generates some energy resulting in the negative parts in the figures (we have assumed that the generated energy replaces heat from coal and oil). Chicken is the most energy-demanding ingredient of both meals, and despite there being more chicken in the homemade meal than in the hash, the total energy use is still lower for the homemade meal due to the large energy use in industry and retail for the semi-prepared meal. As the steps after the farm are important in both meal types, the changes made in the improved scenarios have a significant impact on the total energy use. For the homemade meal, total energy requirement is lowered by about 15%, mainly due to less consumer transport, more efficient household cooking and reduction in packaging material. For the semi-prepared meal, the reduction is more than 20% due to less consumer transport and packaging and reduction in industry. Overall, for both meals, the improvement measures did have quite a large effect in terms of reduced energy requirement.

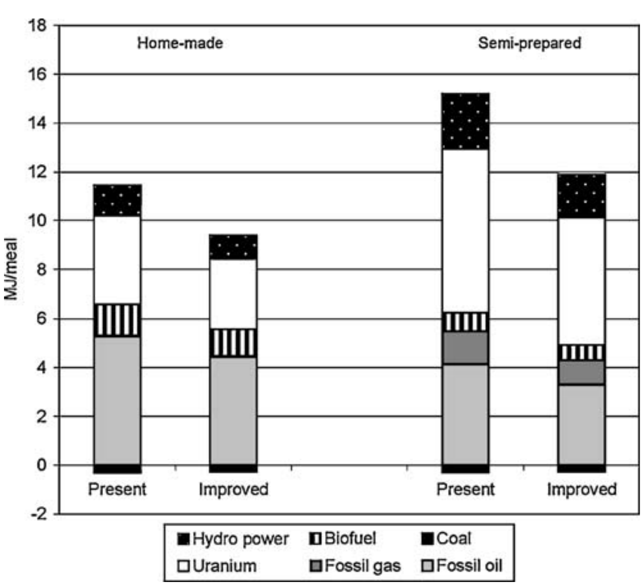

Fig. 2 Primary energy use of each chicken meal (MJ/meal)

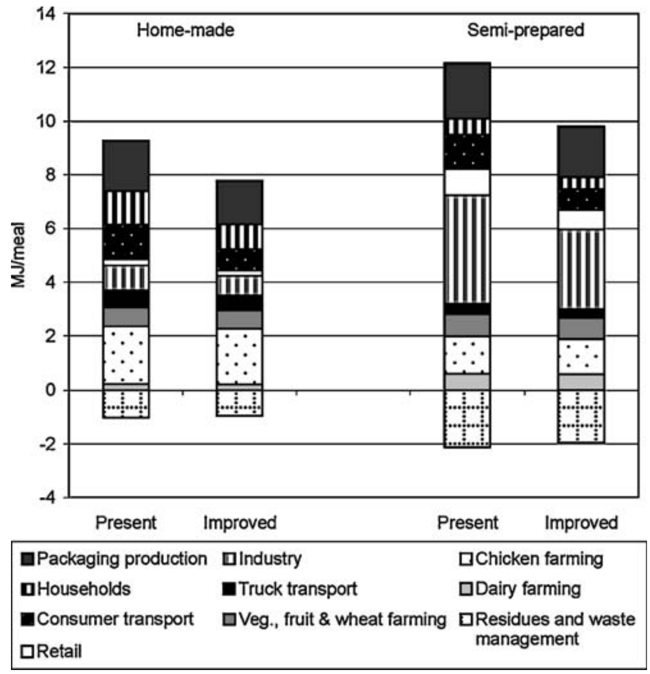

Fig. 3 Secondary energy use of each chicken meal (MJ/meal)

When analysing the global warming potential (GWP), Fig. 4, agriculture is a significant contributor; apart from the energy use in agriculture, there are also emissions of N_2O from production of nitrogen fertilisers and emissions of CH_4 from the dairy cows. For the homemade meal, about 40% originates from agriculture, whereas it is about 50% in the semi-prepared meal (less chicken but more milk than in

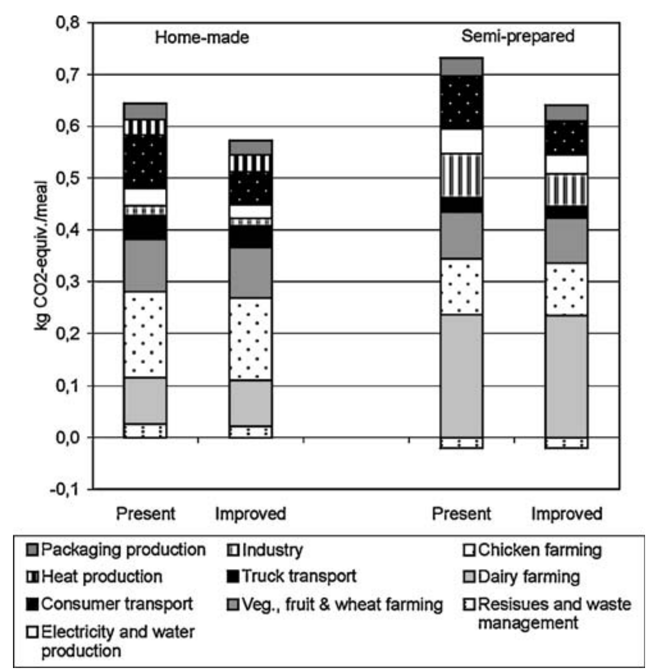

Fig. 4 Global warming potential of each chicken meal (kg CO_2-equivalents/meal)

the homemade meal). Consumer transport is also a significant contributor to GWP for both meal types. The amount of energy that is generated due to treatment of residues and waste is larger in the semi-prepared meal; this results in a negative contribution to GWP for this meal type. The reason is that it is assumed that the energy generated from waste treatment replaces combustion of oil and coal. Overall, the post-farm improvement measures result in about 10% less contribution to GWP for both meal types. The improvement action with the greatest impact is less consumer transport and, in the case of the semi-prepared meal, the reduction in energy use in industry.

When it comes to contribution to eutrophication, see Fig. 5, almost all emissions originate from agriculture; in all scenarios, agriculture stands for more than 90% of the emissions. Hence, the only improvement action that matters here is the utilisation of raw material downstream in the production chain. In the future scenarios, it was assumed that the food wastage be reduced by 5% in industry and by 10% in the households. This very slight improvement still has an effect on the overall contribution to eutrophication; the impact of both meal types is reduced by 4%. Accordingly, if greater improvements are made in terms of minimising wastage along the supply chain after the farm, this reduction will be even larger.

Ammonia is an acidifying substance emitted from livestock production; this is the reason for the chicken and dairy farm being the largest contributors to acidification potential (Fig. 6). Again, as agriculture is the most significant stage here, it is the reduction in waste that lowers acidifying emissions the most.

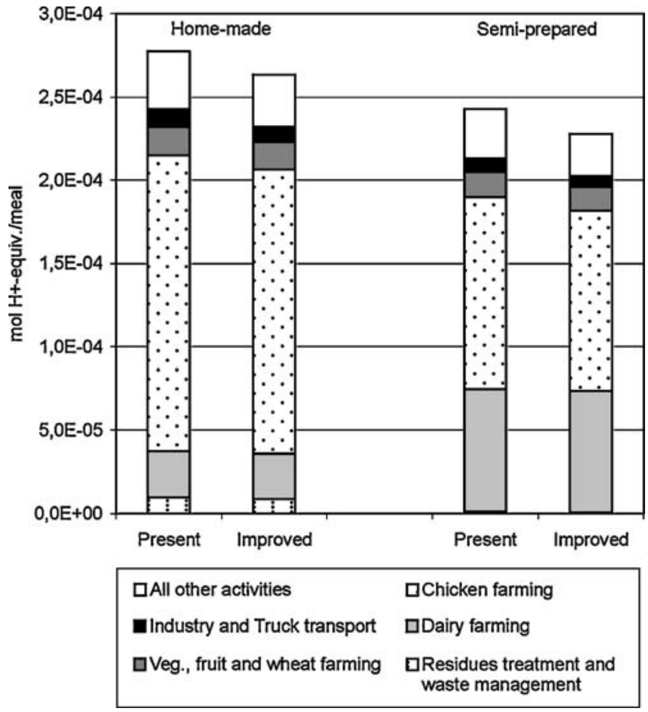

Fig. 6 Acidification potential of each meal (mol H^+-equivalents/meal)

Regarding photochemical ozone creation potential (Fig. 7), the most significant stages are production of packaging and industry, which is related to the production

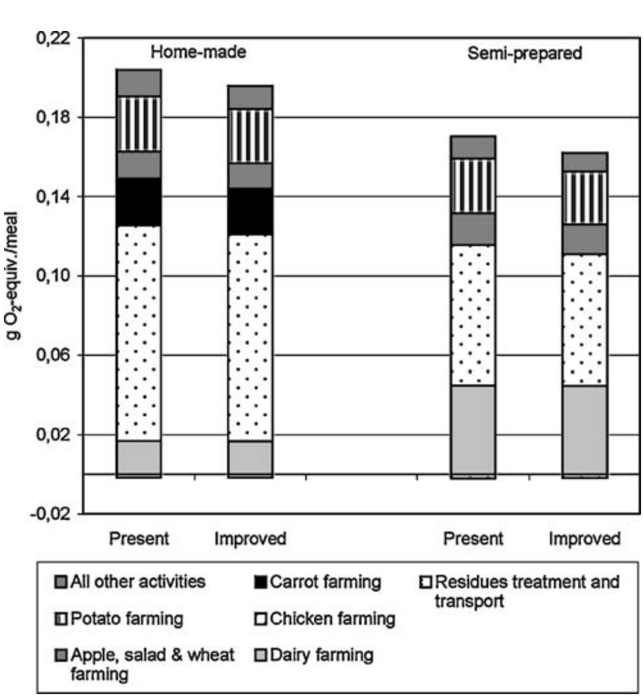

Fig. 5 Eutrophication potential of each chicken meal (g O_2-equialents/meal)

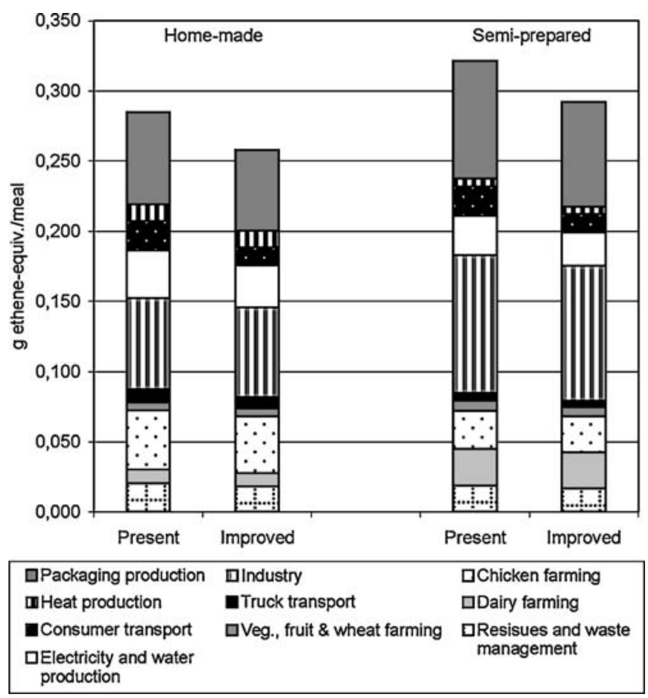

Fig. 7 Photochemical ozone creation potential of each chicken meal (g ethene-equivalents/meal)

of plastic packaging and the energy use in industry. Hence, by lowering the packaging weight only slightly and the energy use in industry, this environmental impact is reduced by about 10%.

4 Discussion

In the analysis, two meal types based on chicken have been studied. If the animal protein ingredient had been pork or beef, the results would have been slightly different. As chicken farming stands for a smaller part of the total environmental impact of the studied meals (due to chicken production having a lower environmental impact compared to other meats), the effects of post-farm improvement measures are greater in this study (not in absolute terms, but in relative terms). Moreover, the conditions are for Sweden using Swedish goals as a basis for the actions. Studies in other countries might come to other findings. Still, most developed countries are likely to have similar production methods and distributions systems and could nevertheless use the results to find insight in where improvement measures are best focused.

In the meals, minor ingredients have been omitted (vegetable oil and the brown sauce mix). The flows of these ingredients are negligible, and it is unlikely that we would have come to other conclusions had they been included. Nevertheless, this delimitation means that the environmental impact of each meal is slightly underestimated.

In the improved scenarios, it was assumed that the shopping frequency by car be reduced from 0.9 times a week at supermarkets and twice a week at neighbourhood retailers to only once a week at supermarkets. In order to achieve this, consumers would have to plan more and perhaps buy fresh products (fruit, bread, etc.) on foot from a local shop. This might not be feasible for every household, but environmentally, it would be a vast improvement in the food chain if we could succeed in economising our car trips.

Reducing food wastage proved to be an important factor in reducing the environmental impact of each meal, especially in terms of reducing eutrophication and acidification potential. The reason is that less produce was needed from agriculture and that agriculture stands for a dominant share of the total eutrophying and acidifying emissions of the two meals. Consequently, if more dramatic cuts can be made in wastage, there are very large potentials in environmental savings. Again, this depends to a great extent on consumer patterns; the household is the last stage in the food's life cycle; hence, all food that is wasted here means that the environmental impact that has occurred all along the chain to deliver the food to the household has been in vain. More awareness and better planning could lead to less wastage in the household. But the industry and retailing sector also have a responsibility in ensuring that packages of food in the right size and quality are available for consumers, e.g. packaging that enables long shelf life and is designed to reduce food waste left in the package. There might be a conflict of less consumer transport and less wastage; would a reduced shopping frequency result in more food wastage? More research is needed to explore this question.

The ambition to reduce all truck transport by 20% (in effect reduce fuel consumption by 20%) only resulted in a minor decrease in the selected impact categories. However, transport causes negative effects not covered in this study (noise, accidents, etc); hence, to reduce transport is still an important goal.

Data on average Swedish electricity production mix was used for the electricity used in the food chains. Swedish electricity production is mainly based on hydro and nuclear power, which, apart from energy use, have a low contribution to the environmental impact categories considered in this study. If the energy use is reduced in a system, it might be argued that it is the marginal electricity production that is being reduced, e.g. electricity produced by combustion of oil, which in turn would give a more significant impact on reduction of environmental impact in the improved scenarios. However, by using average Swedish electricity mix, the effect of the improvement measures has, at least, not been overestimated but, more likely, slightly underestimated.

The delimitation of not including pesticides in the study gives a somewhat incomplete picture of the environmental impact of each meal. In terms of improvement measures, it is however still possible to conclude that a reduction of wastage along the food chain would also result in less use of pesticides.

The improvement measures assumed in the improved scenarios have been judged to be realistic goals. For some measures, even quite modest assumptions have been made, e.g. reduction in food wastage. However, they all require an effort from the different stakeholders in the food chain. The alliance, Future Trade, is a step in the right direction, even if signing an agreement is one thing and achieving the goals is another. Furthermore, in order to fulfil the improvements on household waste and consumer car trips, consumers need to be encouraged to make this effort—which can be quite a challenge.

5 Conclusions and perspectives

Overall, life cycle assessment is a very useful tool to explore to what extent different improvement actions affect

the environmental impact of the food chain. In this study, the effect of a number of improvement actions in the chain after the farm has been explored. The actions did improve the production system in terms of reducing the environmental impact; some actions gave a larger reduction than others.

For both meals, a reduction in consumer transport proved important. Food wastage was another primary parameter. In the improved scenarios, very modest assumptions were made about reductions in wastage of food in the households and in industry, but this still resulted in notable reduced environmental impact.

The action that was most effective for the semi-prepared meal specifically was the reduction of energy use in industry. The particular meal we chose to study required a considerable amount of energy at the industrial stage, and consequently, a reduction here therefore proved very important. Similarly, for the homemade meal, a great deal of energy was required in the household; here, more efficient home appliances had a large impact.

When exploring improvement measures in the post-farm system of integrated food chains, the relative impact of the measures depends on which ingredients are included in the food chains; if production in agriculture stands for the majority of the impact, e.g. a large portion of beef, the improvement measures will have a lower impact than if agriculture has a smaller contribution, e.g. a medium portion of chicken.

Finally, when aiming to reduce the environmental impact of our food consumption, this study shows that consumer actions, such as reducing car transport when purchasing food, reducing household waste and utilising energy efficient home appliances, prove just as important as industrial actions.

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